A Computational Multi-physics Approach for Whole System Fusion Reactor Simulations

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ABSTRACT

This work is concerned with the development of numerical multi-physics algorithms for the whole-system simulation of magnetically confined plasma in toroidal devices. A key area of interest is the transition of a steady-state plasma to unsteady disruption events which can lead to loss of confinement. The large disparity in spatial and temporal timescales of the physical processes involved necessitates some important considerations. Firstly, initial data for unsteady simulations must be computed from non-trivial, non-linear steady-state solutions to the underlying system of equations. Secondly, since traditional explicit schemes fail to adequately capture the inherent all-mach nature of the flow, some form of implicit treatment is required to by-pass the restrictive explicit timestep. Thirdly, uniform mesh sizing will either be too computationally demanding or will fail to capture the fine behaviours on the small scale and thus adaptive mesh generation must also be considered.

We address these issues in the development of a novel framework that will allow for feasible whole-system tokamak simulations. The objective is to account for all regions of the plasma and vessel (core, edge, and vessel wall) within the same simulation and in a Cartesian frame of reference, which represents a significant departure from current (segregated solutions on physics-driven mesh alignment) approaches on both counts [1]. A key element of this methodology is the generation of steady-state profiles, the discretisation of topologically complex rigid boundaries, and the resolution of disparate length and time scales all occurring in the same framework.

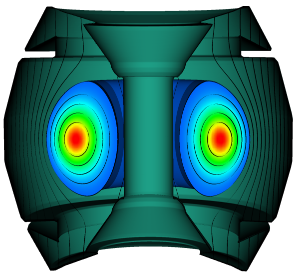

Figure 1: Equilibrium solution for the plasma density shown within the ST40 tokamak reactor geometry.

References

[1] Hoelzl, M., et al, 2021. The JOREK non-linear extended MHD code and applications to large-scale instabilities and their control in magnetically confined fusion plasmas. Nuclear Fusion.